Parachute Drop-Tests and Attitude Measurements of a Scale-Model Huygens Probe from model aircraft

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ABSTRACT

The Huygens probe descent on Titan presented new challenges in understanding the motions of a complex vehicle system in an unknown environment. In particular, the attitude history – which may provide insights into the turbulent variation of winds on Titan – can be reconstructed only by synthesis of various datasets : pointings determined from the camera DISR and transmit antenna gain (both giving attitude fixed to external reference directions) as well as dynamic measurements such as accelerometers and the Tilt sensors on the Surface Science Package.

1. INTRODUCTION

There is no substitute for experience. Our familiarity with parachute-borne probes descending through alien atmospheres is necessarily limited. The development and verification of various systems on probes, such as their parachutes, entails engineering tests which may involve free-flight drops in the Earth's atmosphere, but scientific participation in these tests is rarely solicited and the goals of the tests are often narrowly defined.

To make sense of unfamiliar datasets, and to simply get an idea of how instruments or systems might be better designed or operated, it is useful for scientists to conduct drop tests on Earth. Full-scale balloon-drop tests and/or sounding rocket launches offer substantial capability and in some cases dynamic similarity (in the Reynolds/Mach number sense) with planetary flights. However, these are expensive, and thus rarely occur.

Here we describe the apparatus and results of small-scale parachute drop tests. Modern instrumentation and data recording equipment is compact.

Previously we have described indoor parachute drop tests [1] using microcontrollers as dataloggers, off-the-shelf parachutes (sold for recreational model rocketry) and small sensors. These were extended to packages dropped from a small radio-controlled aeroplane [2] and similar sensors and data acquisition techniques have been used to study the dynamics of Frisbees [3] boomerangs and skipping stones [4].

Here we describe further progress in this experiment programme. More advanced sensor packages have been air-dropped, but this time installed in a scale model of the Huygens probe descent module. This model is a fibreglass shell, patterned on a 1/7 scale model of the probe previously used in splashdown and wave dynamics tests[5].

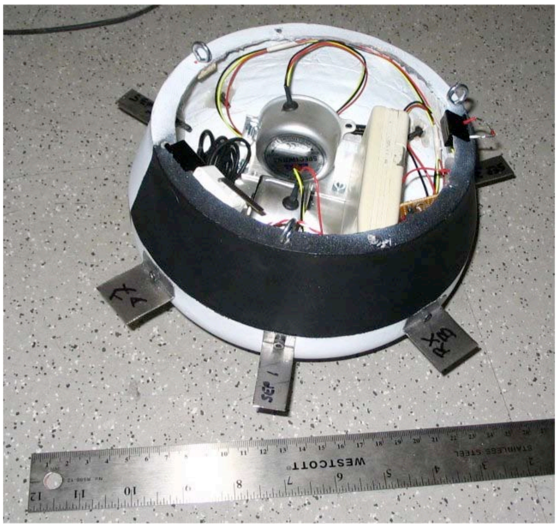

Figure 1. The scale model fibreglass shell with tilt sensors and datalogger. Note the small steel plates installed on the perimeter to simulate the separation fittings and radar altimeter antennae on the real probe.

Additional experiments, with a down-looking sonar, have so far been unsuccessful.

2. MODEL

Our previous experiments used cuboidal packages encased in plastic or polystyrene foam. Here we made a fibreglass shell, a scale model of the Huygens probe descent module (18cm in diameter). A mould was made around an existing delrin model, and glass fiber sheets were laid in the mould with an epoxy binder. (The model had to be made as an upper and lower half, with the join at the probe equator, its largest diameter.)

The resulting shell is very lightweight but is extremely hard and tough (it can be thrown as hard as one can onto a concrete floor with only abrasion as a result.)

The instrumentation is in fact a fairly tight squeeze – the ad-hoc packaging is not as dense as it could be and entails separate batteries for each datalogger, one for the sensor excitation, and a 12V battery for the video camera.

We have used a variety of parachutes. Mostly we have used a spherical chute (from Spherachutes, Inc.) It is made of 8 gores, each of length 28 inches and 14 inch circumference : the canopy has a 5 inch vent hole. Rigging lines were 40 inches long, with a 2 inch strop. A metal swivel, 19g in mass and 3 inch long partly decouples the probe rotation from the parachute. The parachute assembly weighs 193g.

3. SENSORS AND ELECTRONICS

We used two Pace XR-440 data loggers, a unit we have used in previous experiments in wave dynamics tests (Lorenz, 2003). These have proven to be exceptionally reliable in the field (more so than the home-made microcontroller systems we have also used).

These can each record data at up to 200 samples per second on 4 analog (0-5V) channels. They can be triggered immediately, after a delay, or on connection of a thermistor across channel A. Initially, we used the latter mode, with the thermistor held open circuit by a microswitch which closed upon release of the probe. However, vibration during take-off sometimes caused premature triggering, and our later efforts have used preset time delay. Data can be recorded at 8,10 or 12 bits precision.

The datalogger could be much more compactly installed in the probe by removing it from its plastic case. Adhesive tape was applied to prevent the circuit board from encountering shorts.

Although it formed the mainstay of our previous campaigns, we have so far been unlucky with data recording using a BX-24 microcontroller of the output from an O-Navi Gyrocube inertial measurement unit : software misconfigurations caused some early problems and our most recent campaign was thwarted by a hard landing which damaged the BX-24 (the probe restraint system failed just after takeoff, and the parachute did not inflate completely before impact.) A BX-24 was also used in a pre-Huygens attempt to acquire some flight sonar data, but somehow failed.

The sensors used (in various combinations) on the probe have included:
- 3-axis accelerometer (Crossbox CXL04)
- pressure sensor (Omega MPX138-014A)
- two Spectrotilt liquid-in-tube tilt sensors
- an electret microphone
- a thermistor
- a photodiode used as a sun sensor

The entire package weighs about 1260g.

4. FLIGHT CONDITIONS AND OPERATIONS

In general our flights have been conducted in the morning to avoid peak traffic times. At the Tucson International Modelplex Park (TIMPA) – a site where we have also conducted field investigations into dust devils (Lorenz, 2004) – it can be chilly (~0C) in winter mornings, or extremely hot (>40C) in summer noon.

Generally the sky is clear, permitting good sun sensor signals. The horizon is not very uniform due to the nearby Tucson Mountains. The area around the airfield is typical of the Tucson area : flat, dusty ground with bushes every couple of meters. Some ranches and recharge ponds of the Tucson Water company are also nearby.

The aircraft with an uprated engine has rather good performance – it can take off across (as well as along) the runway.

Figure 2. Folding the chute.

Drop duration is generally limited by how far one is prepared to bushwack to retrieve the package : in practice drop altitudes of a few hundred meters with descent durations of 1-2 minutes are typical : the plane can climb to the drop position in a similar period.

Figure 3. The probe installed beneath the plane. It is held in place by a pin that is retracted by a servo on command in flight.

The flight is documented by camcorder from the ground, and a wireless video camera on board is recorded on a laptop computer.

Download of the data takes several minutes. To complete a turnaround, the dataloggers must be re-armed, the parachute folded and the probe installed beneath the plane. Another minute or two is needed to carry the plane to the runway and to start the engine. Total turnaround time, in the absence of repairs, traffic delay etc., can be as short as 15 minutes.

Figure 4. Recovery of the probe

4. RESULTS

Our experience is that one is lucky to have all systems work well on a single drop. A combination of video record from the ground, and in-flight, gives a good probability that the flight will be adequately documented.

On this scale at least, even though dynamics parameters such as Mach and Reynolds numbers remain constant, the dynamic behaviour of the probe manifestly does not. Clearly the probe is responding to ambient conditions in the form of winds.

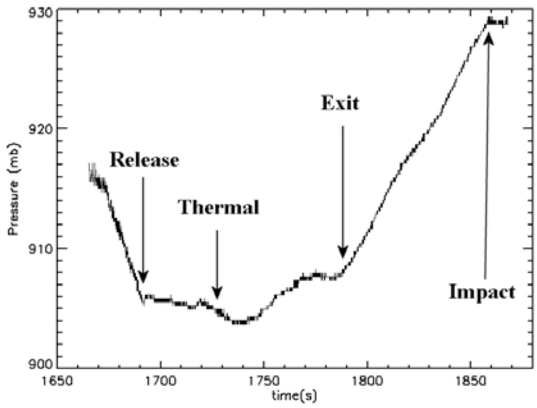

Figure 5. Pressure record from a long (~3 minute) drop – the probe was released during the aeroplane's climb, but did not immediately descend. It was in rising air for around 100s, with a core of ~30s during which the probe itself rose in altitude. Unfortunately the thermistor was misconfigured on this drop.

A good example is the pressure record in figure 5 : the fact that the pressure fell shortly after release indicates the probe ascended – it was obvious from the ground that the probe was simply not coming down. Evidently it caught a thermal (this flight was at around 11.30 local time.)

Temperature data even from an inexpensive thermistor shows another consistent trend – especially in dry air, the lapse rate permits an observable temperature change (e.g. figure 6).

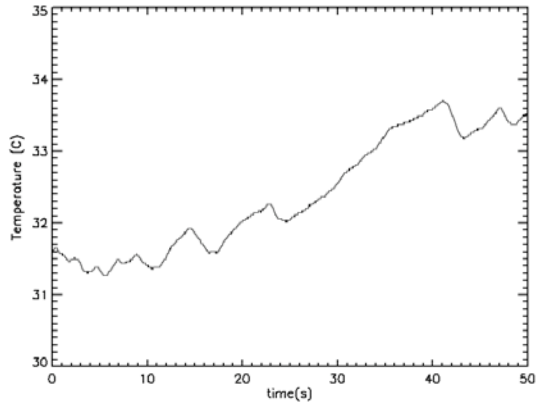

Figure 6. Temperature record from a thermistor on the outside of the probe. In desert conditions, the lapse rate approaches the dry adiabat of 1K/100m and thus a substantial temperature change can be observed. The periodic component of this signal is not understood – it may be due to direct radiant heat from the sun as the probe rotates.

The data from the onboard video camera was remarkably informative, and gives an impression much like the DISR camera on the real Huygens probe – obvious landmarks (figure 7) such as the runway and ramada, a water tower, road junction etc can be used as tiepoints to track relative motion. The relative motion in image space is of course a combination of translation and rotation – deconvolving these two components is laborious and has not yet been investigated in depth since tiepoints must be tracked frame-by-frame in the video record (figure 8).

The camera was aimed at approximately a 45 degree angle – this gives an interesting, but variable, combination of attitude and mapping/translation information. A horizontal-looking camera that (nearly) always showed the horizon might have been better for pure attitude measurement. Contrariwise, a down-looking camera would be better for wind estimation via horizontal translation.

A potential future project is to write automatic image correlation software to determine translations or rotations from the video record without laborious manual input.

Figure 7. Videopoint software was used to track feature locations

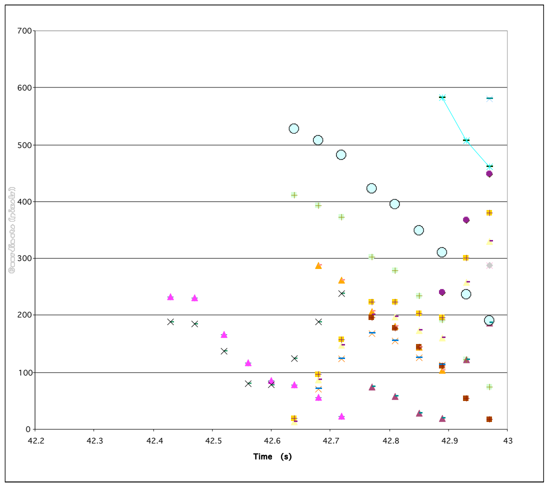

Figure 8. Pixel coordinates of various features can be plotted vs time.

The tilt sensors were surprisingly uninformative. The settling time is reported in manufacturers data as <1 second, but it seems that the sensors do not respond to rapid tilts : a muted periodic signal was seen on release, but of far lower amplitude than was obvious from other data.

Accelerometry is a common dataset on planetary probes. At least some recognizable signatures are evident. Figure 9 shows the X-axis (longitudinal) accelerometer output with a transient pendulum motion, apparently excited by air motions. Figure 10 shows the corresponding Y and Z axes.

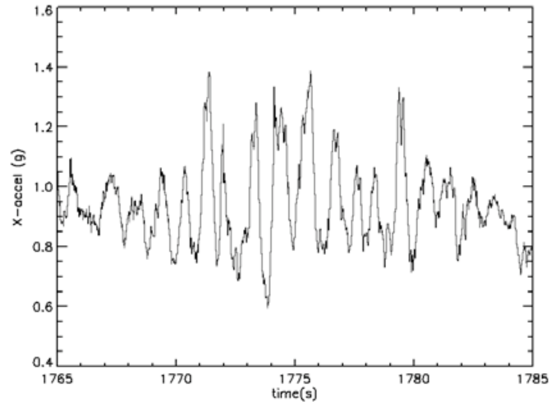

Figure 9. Axial accelerometer showing pendulum signal.

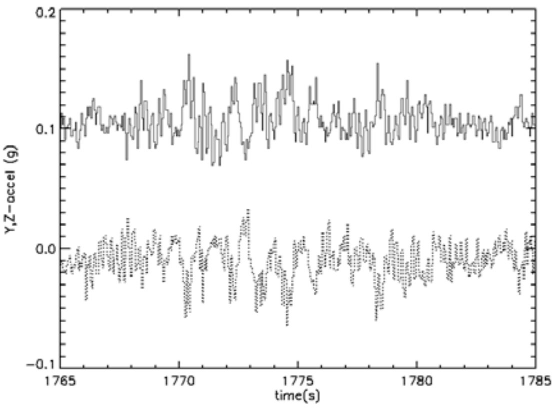

Figure 10. Transverse accelerometer. Notice that the periodicity is less obvious in these data than in the axial accelerometer record.

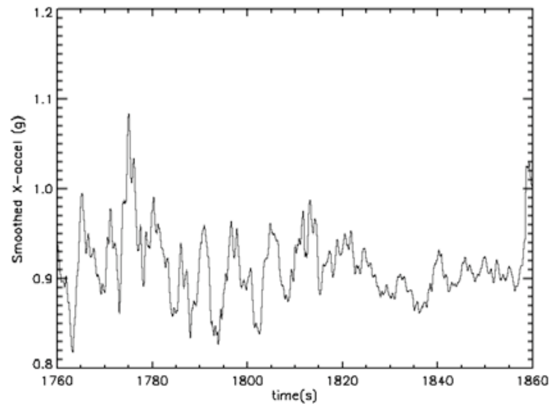

Figure 11. Smoothed X-axis accelerometer record (same drop as Figure 9). Data are smoothed with a 2s boxcar – a periodicity of ~8s is evident. The cause of this period is not known.

So far a good combined pressure-temperature-sun-sensor drop has not been captured, so the correlated climb and sun-corrected temperature has not been investigated.

The sun sensor, a simple CdS light-dependent resistor forming a potential divider, was useful only as a sun presence detector – indicating when the sun was in the visible hemisphere of the sensor – it thus gives an indication of spin. Figure 12 shows some example data.

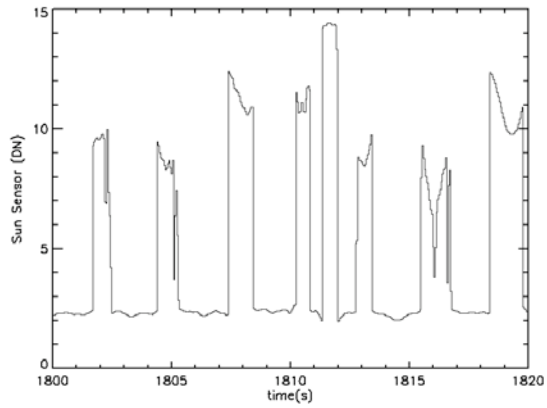

Figure 12. Sun sensor output.

The video record has an enormous amount of dynamical information, but so far has proven a lot to digest. However, its visual impact in presentations is excellent, and some neat observations can be made which can be compared with real flight experience – the auto-exposure behaviour of the camera, especially during takeoff is reminiscent of that of the Huygens probe DISR. The probe or parachute's shadow is also visible (figures 13,14) – the shadow and halo during terminal descent was observed by MER.

Figure 13. Self-portrait shadograph of the probe immediately before impact.

Figure 14. Shadow of the parachute when at an altitude of ~20m. The shadow can be seen moving from frame to frame. Note also an 'opposition effect' brightening around the shadow.

5. CONCLUSIONS AND LESSONS LEARNED

This work represents a significant improvement on our previous efforts – better instrumentation and dynamic similarity, with longer flights and better documentation. As before, these experiments are yielding insights into the behaviour of planetary probes.

Our experience suggests that one can simply never have too many ways of measuring things. Sensors, data acquisition systems as well as nonelectronic systems are all prone to failure. As a general principle, we attempt to deploy three systems, in the hopeful expectation that a couple will work.

Further, it is best to bring everything to the field – failures are generally unanticipated, and it is often easier to just throw everything in a box and bring it just in case, than to think through what failures are most likely to occur and prepare only for those.

Simplicity is a major virtue in both hardware and software. Timed sampling has been much more robust than clever triggered schemes – on only a few occasions has data been lost or a test aborted due to missing the sampling window.

Bright colours (white and orange) were vital for reliably detecting the chute in the sky, and especially for its recovery.

It was not always obvious a priori which sensors would provide the most interesting data. For example, both the on-board video and the thermistor proved to be more interesting than anticipated, while the tilt sensors much less so. An evolutionary approach where the results of one day's testing can be fed into the configuration of the next tests allows effort to be directed in the most productive directions.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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